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Full Length Research Paper

Performance of wastewater treatment plants in Jordan and suitability for reuse

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There is an increasing trend to require more efficient use of water resources, both in urban and rural environments. In Jordan, the increase in water demand, in addition to water shortage has led to growing interest in wastewater reuse. In this work, characteristics of wastewater for four wastewater treatment plants were determined. Characterization of wastewater was evaluated in terms of measuring BOD, COD, TSS, TDS, NH_4, and DO for the influent and the effluent wastewater from the selected plants. The quality of the treated wastewater was compared with Jordanian standards. Results indicate that municipal wastewater in Jordan contains high concentrations of pollutants such as BOD, COD, TSS, and NH_4; therefore it is classified as a strong waste. The performance of the four treatment plants was evaluated. Conventional and modified activated sludge show good performance, while low water quality is produced by stabilization ponds. The effluent from activated sludge treatment plants complies with Jordanian standards for restricted use. Before reuse, effluent wastewater needs advanced treatment to prevent its impact on human health and the environment.

Key words: Wastewater, treatment plants, water reuse, wastewater characteristics, wastewater treatment, Jordan.

INTRODUCTION

Jordan population has increased rapidly from 0.58 million in 1950 to more than 5.6 million in 2006. This increase has resulted from the high growth rate of 3.1% annually and the successive immigrations from Palestine in 1948, 1967 and from Kuwait in 1990 (Statistical Department, 2006). Jordan has faced the problem of water scarcity for many years, and improving the efficiency of water use is an important part of its effort to deal with the problem. The total average precipitation volume is about 8.5×10^9 m^3/y; however 92% of this quantity is lost via evaporation (Al-Zboon, 2002). Water consumption has increased, as a result of population growth and development projects, while the available sources of water are limited and decreasing year after year. In the year of 2000, the demand of water was estimated to be about 1100 millions m^3 (MCM), while the available water from all sources (surface and ground water) was less than 850 MCM, indicating a shortage of water of 250 MCM. The shortage of water has affected the individual consumption. For example the water consumption in the year of 1998 was about 160 m^3/capita/y and is expected to fall to 90 m3/capita/y in 2020, which is very low in comparison to the international per capita consumption level of 1000 m^3/y (Al-Zboon, 2002). The agricultural demand of water is estimated to be 73% of the total water consumption, while 22% of water is used for domestic needs and only 5% is used for industrial sector (WAJ, 2006).

This increase in water demand combined with the limitation of water resources lead to development of available water resources. Currently, the interest in wastewater reuse in various parts of the world has promoted the

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development of wastewater and secondary effluent treatment technologies (Janga et al., 2005, Simon, 2006). The main purpose of wastewater treatment is to prevent pollution of the receiving watercourse, and to protect human health and the environment (Metcalf and Eddy, 1991). The reuse of reclaimed wastewater is an international practice. Reclaimed wastewater is applied on soil, on cultivated as well as marginal areas in various facilities, in irrigation, industry, and for recharge of ground water (Kalavrouziotis and Apostopoulos, 2007; Bushnak, 2003; Salgot et al., 2006; Ernst et al., 2007). The integrated and safe application of the reuse of reclaimed wastewater from wastewater treatment plants (WWTPs) dictates the development of a comprehensive environmental plan, which will take into consideration all parameters relative to such reuse, qualitative characterization of wastewater as well as examination of physical-chemical and environmental properties of all applications on soil, plants, building installations, and pipes (Kalavrouziotis, and Apostopoulos, 2007; Salgot et al., 2006; Magalha et al., 2005). Due to the more and more pronounced water deficit, the reuse of wastewater in the Middle East countries is part of the strategy for the conservation and development of water resources. Moreover, the experience of these countries in this domain has proved the feasibility of the reuse procedure (Bataineh et al., 2002; Jemali and Kefati, 2002; Alatiri et al., 2002).

The characteristic of wastewater depends considerably on the type of sewer collection system (combined or separate), industrial waste entering the sewer, type of wastewater treatment technology, the quality of domestic fresh water, and the standard of living of consumer's community. The degree of required treatment is determined by the beneficial uses of the receiving stream, lake, and reuse for different purposes (Hammer, 1996). Therefore, the investigation of the characteristics of the reclaimed wastewater is necessary for evaluating its suitability for reuse.

In Jordan there are twenty three municipal treatment plants, which cover most of the major cities and towns. These plants serve about 56% of the population. The total inflow to these plants is around 216,412 m^3/d, of which 186223 m^3/d inflow to Asamra wastewater treatment plant (ASTP) (Bataineh et al., 2002; Asa'ad, 2006). Jordanian standards for reclaimed wastewater (JS893/1995) try to regulate both water reuse and environmental discharges. Jordanian standards allow discharging treated wastewater to valleys and streams when it meets the specific criteria for many parameters such as BOD, COD, TSS, *Escherichia coli* bacteria, and helminthes eggs. In the present time, the reclaimed wastewater is used for restricted agriculture either near the plants or downstream after mixing with natural surface water (Bataineh et al., 2002). More than 70 million m^3/year of reclaimed water, around 10% of the total national water supply, is used either directly or mostly indirectly in Jordan and will increases to a share of more than 15% within the next 30 years (Bataineh et al., 2002; Bdour and Hadadin, 2005; McCornick et al., 2007; Ammary, 2007). Therefore, water reuse is considered an attractive option for increasing the available water resources of Jordan

In this study, characteristics of wastewater for four wastewater treatment plants, which are Al-Samra (ASTP), Irbid (ITP), Ramtha (RTP), and Wadi Hassan (WTP) were determined. Characterization of wastewater was evaluated in terms of measuring chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), and dissolved oxygen (DO) for the influent and effluent from the selected plants. The performance of the four wastewater treatment plants (WWTPs) was evaluated and the quality of the reclaimed wastewater was compared with Jordanian standards to determine its suitability for reuse.

MATERIALS AND METHODS

The selected plants treat about 90% of the domestic wastewater in Jordan and serve more than 2 million inhabitants (Bataineh et al., 2002). ASTP utilizes stabilization ponds as the treatment process as shown in Table 2. Because ASTP is the largest plant in Jordan and treat more than 76% of collected municipal wastewater, most of the environmental studies concentrate on the performance of this plant and the possible actions to enhance its efficiency. The plant consists of three parallel trains with total areas of 181 hectare (Asa'ad, 2006). There are two aerobic ponds, four facultative ponds, and four maturation ponds in each train. The effluent from the plant to the Zarqa River represents more than 80% of the total flow in the river during dry weather. River's water contains high concentrations of organic matter, inorganic minerals, salts, and heavy metals (Al-Zboon, 2002). The other treatment plants, which are ITP, RTP, and WTP, are operated as activated sludge with different modes as shown in Table 2. In order to determine the characteristics of wastewater for the selected plants, representative weekly samples were taken from the inlet and outlet of these plants during June 2005 to march 2006. Samples were analyzed in the environmental laboratory at AL-Huson College according to the Standard Methods (APHA, 1985). BOD and TSS are the most important parameters used to define the characteristics of municipal wastewater.TDS, NH_4, and DO are used as indicators for the suitability of wastewater for reuse. Representative samples were collected very carefully to avoid agitation or any contact with air. Glass bottles with 300 ml volume with ground glass stopper and flared mouth were cleaned, dried and then used for samples. Samples were transported to the laboratory and analyzed as soon as possible. If delay before analysis was expected, the samples were preserved and stored according to the recommended procedure in the standards methods. After dilution, the BOD samples were incubated at 20°C for 5 days. The change in DO concentration during the incubation period was measured to determine the BOD concentration. Closed reflux method was used to determine COD concentration. Culture tubes were washed and caped with H_2SO_4.Then the samples tubes were put in a block digester preheated to 150°C and refluxed for 2 h. After digestion period, the samples were cooled to the temperature room and titrated by 0.1

Table 1. Wastewater treatment plants in Jordan.

No.	Plant	Hydraulic design capacity m^3/d	Operating capacity m^3/d	R**	Type of treatment
1	ASTP	68000	224175	330	WSP
2	$Aqaba_1$	9000	6229	69	WSP
3	Mafraq	1800	1866	104	WSP
4	Ramtha	5400	3492	65	AS
5	Ma'an	1600	2644	165	WSP
6	Madaba	7600	4584	60	AS
7	Irbid	11000	6353	58	TF+AS
8	Karak	785	1618	206	TF
9	Baqa'a	12000	10978	91	TF
10	Tafila	1600	1012	63	TF
11	Kufranja	1900	3387	178	TF
12	Salt	7700	4322	56	AS
13	Jerash	3500	3312	95	AS
14	Abu-Nusir	4000	2309	58	AS
15	Fuheis	2400	1684	71	AS
16	Wadi Musa	3400	1670	49	AS
17	Wadi Hassan	1600	1098	69	AS
18	WadiArab	22000	9960	45	AS
19	Wadi Al-Sir	4000	2718	68	AL
20	$Aqaba_2$	12000	6952	58	AS

**R = Applied hydraulic load/design hydraulic load x 100%.
WSP: Waste Stabilization ponds, TF: Biological filter, AS: Activated Sludge, AL: Aerated Lagoon.

Table 2. The treatment plants concerned in the study.

Plant	Treatment process	R*	Remarks
Al-Samra	Stabilization ponds (natural aeration, facultative, anaerobic lagoons)	330	
Irbid	Screen, grit removal, primary sedimentation, biological process, secondary sedimentation, disinfections	58	Trickling filter +Activated sludge
Ramtha	Screen, grit removal, biological process, secondary sedimentation, Polishing pond, infiltration, disinfections	65	Activated sludge with nitrogen removal technique
Wadi-Hassan	Screen, grit removal, biological process, secondary sedimentation, polishing pond, disinfections	69	Activated sludge –Oxidation ditch

*R = Applied hydraulic load/design hydraulic load x 100%.

molarity of Ferric Ammonium Sulfate (FAS) standard. The titration process was continuing until the color of samples changed from blue-green to reddish-brown. In order to determine TSS and TDS concentrations, samples were filtered through a weighed standard glass-fiber filter with 2 μ diameter. The filtrate was evaporated to dryness in a weighted dish and dried at 180°C. The increase in dish weighted represents TDS weight. The residue on the filter was dried at 105°C. The increase in the weight of the filter represents the total suspended solid.

RESULTS AND DISCUSSION

The average values of BOD, COD and TSS concentrations for the influent wastewater are 880, 1946, and 795 mg/L, respectively (Table 3). Based on these values, wastewater in Jordan is classified as a strong wastewater where the concentration of pollutants is much higher than the international figures. The ASTP, ITP, RTP, and WTP plants had been designed to receive BOD concentration of 520, 600, 800, and 1000 mg/L respectively (WAJ, 2006). This variation between applied and designed values caused unexpected deterioration in plants performance.

Figure 1 shows the effluent BOD values for the selected treatment plants. It can be seen that the BOD value ranges

Table 3. Wastewater characteristics for the plant concerned in the study.

	Al-Samra	Irbid	Ramtha	Wadi Hassan	Average
BOD in (mg/L)	705	1030	915	870	880
BOD out (mg/L)	140	32	13	12	49
BOD removal %	80	97	98	98	93
COD in (mg/L)	1890	2205	1980	1710	1946
COD out (mg/L)	605	110	70	63	212
COD removal %	67.8	95	96	96	89
TSS in (mg/L)	591	1040	780	770	795
TSS out (mg/L)	117	51	30	25	56
TSS removal %	80.2	95	96	96.7	92
NH_4-N in (mg/L)	90	108	90	118	102
NH_4-N out (mg/L)	97	12	1	4	28
NH_4-N removal %	*	88	99	96.6	95
DO out (mg/L)	1.8	3.9	4.3	5.8	4

*Effluent concentration higher than the influent.

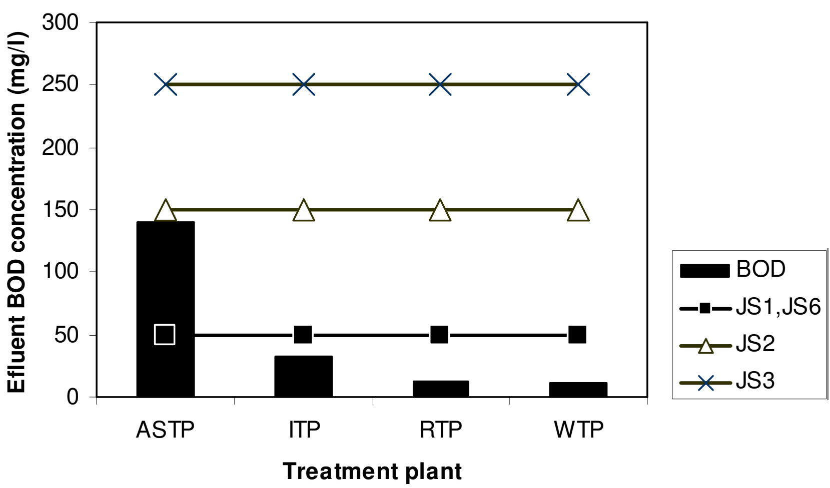

Figure 1. Comparison between effluent BOD and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

from 140 to 12 mg/L where the highest value is for ASTP. The effluent from ITP, RTP, and WTP complies with Jordanian standards for reclaimed wastewater discharge to streams, ground water recharge, irrigation parks, reuse for irrigation of cocked vegetables, fruits, and trees, and for reclaimed wastewater reuse for fodder crops. Effluent from ASTP does not comply with Jordanian standards for water discharge to streams, ground water recharge, and irrigation parks or for unrestricted irrigation as shown in Figure 1. The effluent from the plant is discharged to Wadi Al-Dhlil which meets Zarqa River at Al-Sukna location. This water is mixed with other tributaries along the river that improve its quality, but in all cases the pollutants concentration remain high and above the allowable limits.

A similar behavior to the one that was observed for BOD values is obtained for COD and NH_4 values for the effluent from the WWTPs as shown in Figure 2 and Figure 3, respectively. The effluent from ITP, RTP, and WTP complies with Jordanian standards while the effluent from ASTP does not with regard to the obtained COD and NH_4 value. The effluent from the selected plants has a

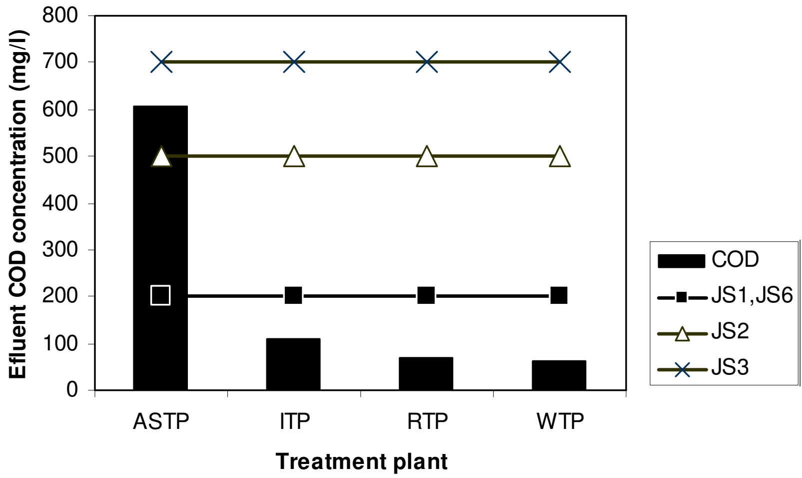

Figure 2. Comparison between effluent COD and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

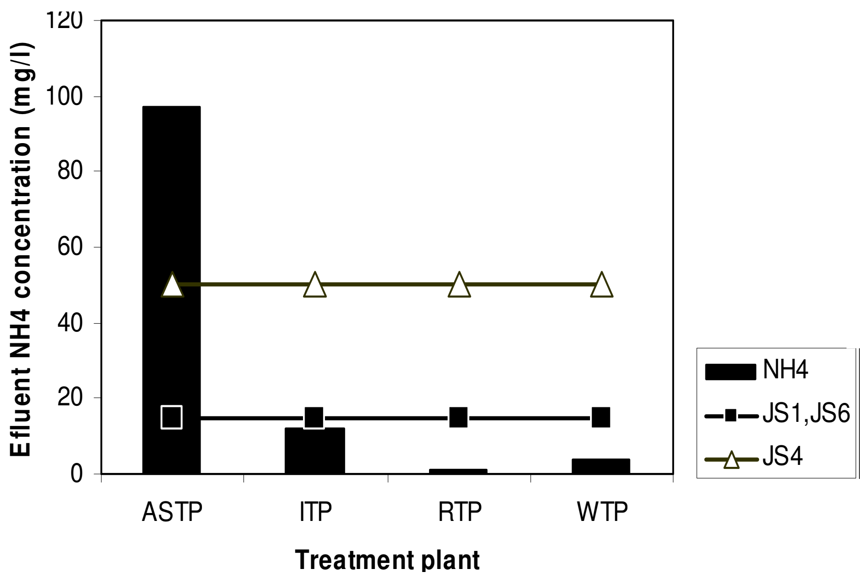

Figure 3. Comparison between effluent NH_4 and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

high concentration of TSS which does not comply with Jordanian standards for fishponds as shown in Figure 4. On the other hand, the concentrations of TSS for the effluent from the four plants comply with Jordanian standards for cocked vegetables, fruits, trees, and fodder crops. With respect to Jordanian standards for discharge to streams, ground water recharge, and irrigation parks, the TSS concentration in the effluent from ITP, RTP, and WTP matches the previous standard while effluent from ASTP does not. Regarding TDS, results shown in Figure 5 indicate that the effluent from the studied WWTPs has values smaller than the Jordanian standards for discharge to streams, irrigation parks, cocked vegetables, fruits and trees, fodder crops, and ground water recharge. The concentration of DO for the effluents from the studied plants complies with Jordanian standards for fodder crops,

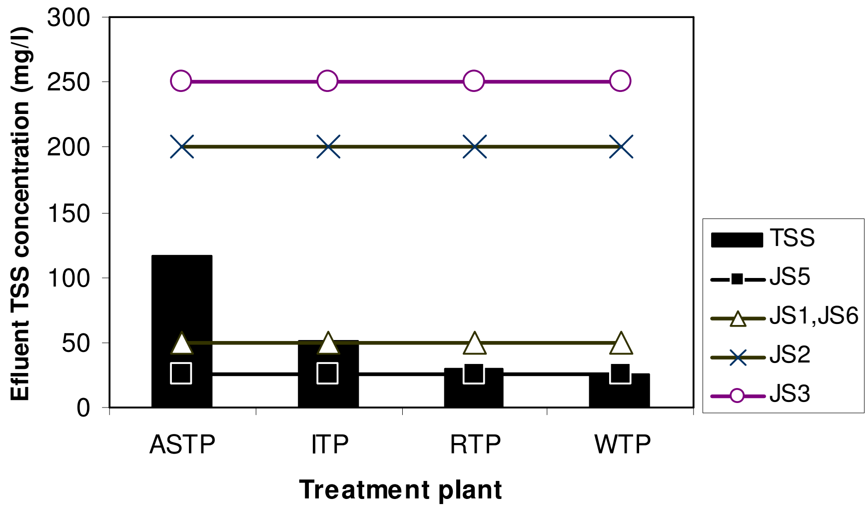

Figure 4. Comparison between effluent TSS and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

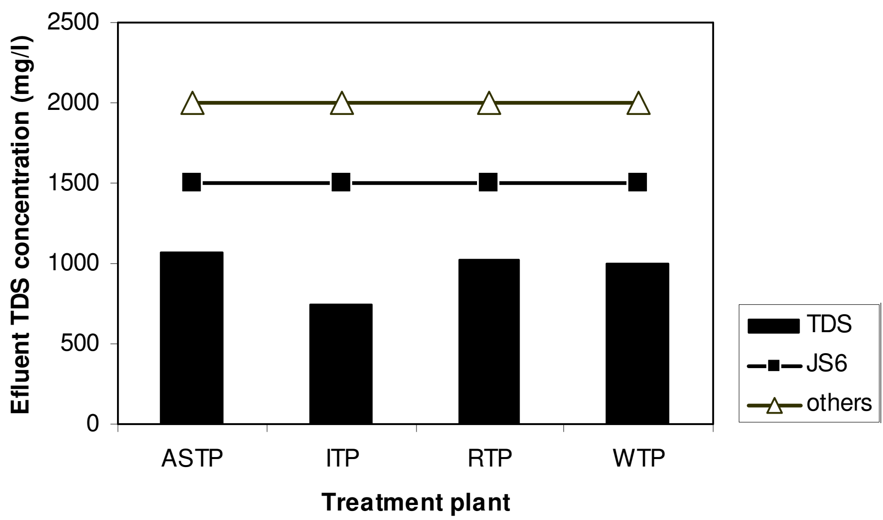

Figure 5. Comparison between effluent TDS and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

for discharge to streams, ground water recharge, irrigation of parks, cocked vegetables, fruits, and trees as shown in Figure 6. With respect to Jordanian standards for fishponds, only WTP has a DO concentration that complies with this standard.

Effluent from ASTP has a high concentration of BOD, COD, NH_4, and TSS as shown in Figures 1, 2, 3, and 4, respectively. This could be related to several possible reasons. ASTP is operated as a stabilization pond and receives an organic load higher than the design capacity see Tables 2 and 3. ASTP was designed to treat 68000 m^3/d and started with 57000 m^3/d in 1985 m^3/d, and reached 186823 m^3/d in 2003 that means the present hydraulic load is more than 2.75 times the design value,

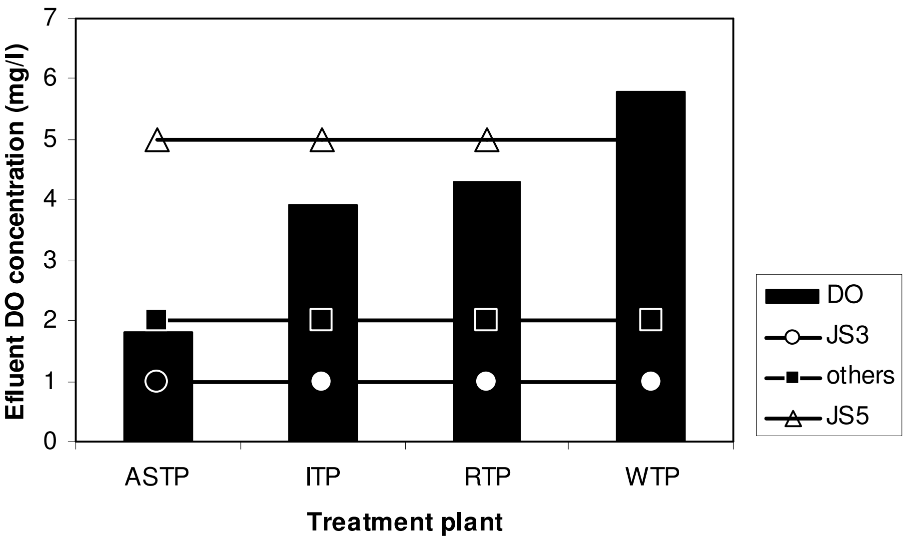

Figure 6. Comparison between effluent DO and Jordanian standards. JS_1: Standard for discharge to streams, JS_2: Standard for cocked vegetables. JS_3: Standard for fodder crops, JS_4: irrigation parks, JS_5: standard for fishponds. JS_6: standards for ground water recharge. Others: Jordanian standards for other uses.

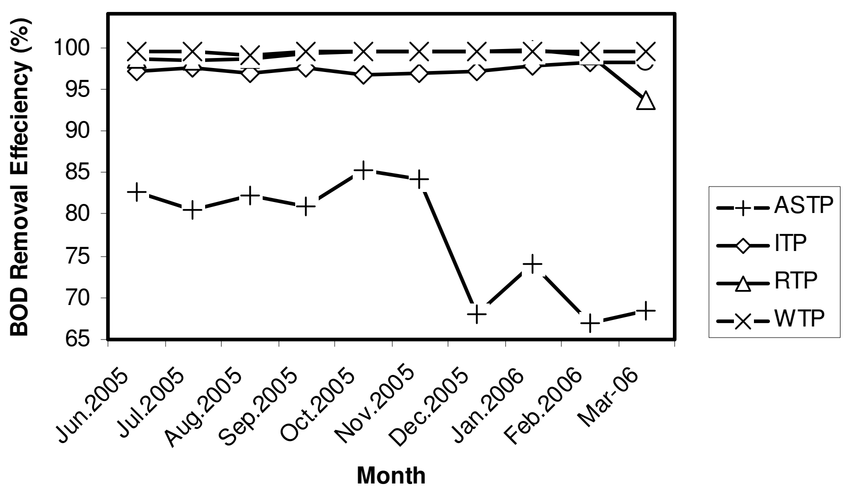

Figure 7. BOD removal efficiency during the study period.

which decreases the detention period in the basins from 42 days to less than 19 days (Bataineh et al., 2002; Asa'ad, 2006). This type of treatment is influenced by climate, where low temperature and short sunshine period during winter will affect the activity of bacteria and algae as shown in Figures 7 and 8. Also, the influent to the plant has a high strength of organic matter due to the low water consumption by population where the available data indicates that the daily consumption is less than 80 l/capita (Al-Zboon, 2002). Illegal discharge of wastewater from some industries, slaughterhouses, and septic tank participate in increasing the concentration of the organic matter. ASTP plant does not have any facility to remove nitrogen which explains the high concentration of ammonium in the effluent stream. For all the previous reasons, the quality of the effluent treated water declined and the removal efficiency of the plant deteriorated. Therefore, the effluent wastewater would be unsuitable for reuse except for limited purposes. It is important to mention that ASTP will be changed to activated sludge

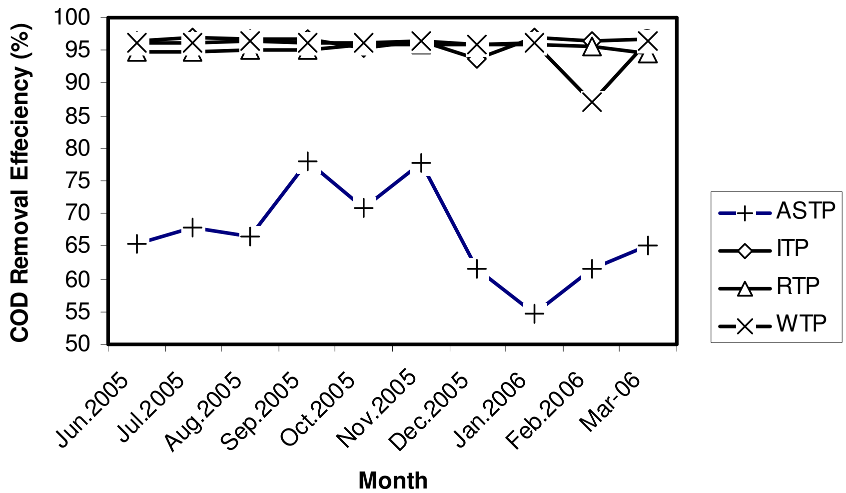

Figure 8. COD removal efficiency during the study period.

mode during the next two years. This change will improve reclaimed water quality in Jordan, and increases the available water resources by more than 110 MCM /y (WAJ, 2006).

The other studied plants are operated as activated sludge where oxygen is sufficient for biological decomposition, also recycled sludge enhance the activity of bacteria. Activated sludge treatment or mechanical treatment is considered as a flexible operating system where the operator has many alternatives and can maintain many parameters in order to achieve the desirable effluent quality. For this reason the water authority decided to convert many stabilization ponds to the mechanical mode such as RTP and Madaba treatment plant. RTP has a modified technique used to remove nitrogen by nitrification denitrification processes.

RTP was constructed in 1987 as stabilization ponds, but as a result of high load, the treated effluent has deteriorated so it was modified and redesigned as activated sludge-extended aeration process, and it started operation in 2003 (WAJ, 2006). A significant improvement in water quality is obtained as a result of plant modification (WAJ, 2006)

Table 1 shows that the ITP, RTP, and WTP plants receive low hydraulic loads compared with ASTP, which ranges between 1098 m^3 /d for WTP to 6353 m^3/d for ITP, therefore these plants have limited importance for water reuse.

Conclusion

Wastewater in Jordan is classified as a strong wastewater. The stabilization ponds treatment plant (ASTP) has low efficiency with regard to BOD, COD, and NH_4 removal where they do not comply with Jordanian standards. A better water quality can be achieved by using activated sludge method (ITP, RTP, and WTP). The effluent from activated sludge treatment plants complies with Jordanian standards for restricted use. Discharged wastewater from the selected plants is not suitable for unrestricted irrigation and it needs advanced treatment before reuse. More research needs to be conducted in order to improve the quality of reclaimed wastewater for different purposes and to increase public confidence.

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